Systemic interest rate and market risk at US banks

Ludwig von la Hausse[1] · Martin Rohleder[1] · Marco Wilkens[1]

Abstract This paper is the first to quantify and analyze the dynamics of market risk (*MR*) and interest rate risk (*IRR*) of the system of US bank holding companies (BHCs) based on time-varying risk exposures estimated using the Kalman filter. These dynamics can be ex-plained to a considerable degree by the development of the macro economy as well as by the state and structure of the banking system itself. We further determine each single bank's contribution to the banking system's *MR* and *IRR* and show that single banks have non-trivial leverage over the banking system's systematic risk exposure at specific times. Such risk contributions can be explained by banks' financing or deposit base, maturity transformation intensity and interest income, earnings diversification and the liquidity of banks' holdings. Our findings thus facilitate better oversight and management of the systematic risks inherent in the banking system.

Keywords Interest rate risk · Market risk · Banks · Banking system

We thank Oliver Entrop and two anonymous reviewers for very helpful comments and suggestions to improving the paper. All remaining errors are our own.

Electronic supplementary material The online version of this article (doi:10.1007/s11573-016-0830-8) contains supplementary material, which is available to authorized users.

Ludwig von la Hausse
Ludwig.vonlaHausse@wiwi.uni-augsburg.de

Martin Rohleder
Martin.Rohleder@wiwi.uni-augsburg.de

Marco Wilkens
Marco.Wilkens@wiwi.uni-augsburg.de

[1] Chair of Finance and Banking, University of Augsburg, Universitätsstr. 16, 86159 Augsburg, Germany

JEL Classification G21 · E43 · G14

1 Introduction and literature review

This paper is the first to quantify and analyze the dynamics of market risk (*MR*) and interest rate risk (*IRR*) of the system of US bank holding companies (BHCs[1]) based on time-varying risk exposures estimated using the Kalman filter. This topic is vital as both types of risk are systematic risks inherent to all banking activities and because timely and precise determination of banks' overall systematic risk exposures is important for immediate reactions to systemic threats. Our findings thus help investors and regulators to better judge possible reactions of *MR* and *IRR* risk exposures of the banking system to the macroeconomic environment and to learn that the structure of the banking system is related to risk exposures beyond macroeconomic influences. We further show that single banks' non-trivial contributions to systemic *MR* and *IRR* can be explained by their financing or deposit base, maturity transformation intensity and interest income, earnings diversification and the liquidity of banks' holdings. Thus, our findings give regulators and investors fulcrums for better oversight and risk management.

In the first part of the paper we therefore estimate the time-series of *MR* and *IRR* betas for the system of US BHCs through cycles from 1997 to 2012 from the portfolio of BHC stock returns. Methodologically, our approach to estimating risk exposures of the system of US BHCs is based on the two-factor models used by Stone (1974) and Flannery and James (1984), respectively, who estimate banks' constant *MR* and *IRR* betas from OLS regressions of bank stock returns and, respectively, relate them to bank characteristics from accounting data in a second-stage analysis.

Flannery and James (1984) have thus set the base for the strand of literature analyzing interest rate risk of banks from the capital markets' perspective using banks' return data instead of relying on accounting gap measures like Toevs (1983) or Kaufman (1984). Staikouras (2006) provides an excellent overview of the related literature for both, market and accounting approaches. A more recent study in that area is, e.g., Bessler and Kurmann (2014) who measure the sensitivity of the banking system's return with regard to a broader set of risk factors including a long-term government bond as a proxy for interest rate risk. They, like Stone (1974) and Flannery and James (1984), find interest rate risk to be a significant driver of bank stock returns at least for some sub-periods. Studies like Flannery and James (1984) and Hirtle (1997), respectively, then show that the cross-sectional differences in magnitude and direction of interest rate exposures of single banks can be traced back to the balance sheet composition or off-balance sheet positions, respectively, of such banks.

In contrast to such cross-sectional approaches, and similar to Entrop et al. (2016) who concentrate only on the *IRR* dynamics of single banks, our empirical analysis

[1] We use the expressions "BHC" and "bank" interchangeably. When referring to banking subsidiaries of BHCs, we use the term "commercial bank".

of the banking system's dynamic risk exposures is based on time-varying betas which are estimated in an econometrically consistent way applying the Kalman filter on a two-factor state space model. Thereby, we extend previous empirical approaches in the time dimension for both *MR* and *IRR* betas. This mitigates econometric issues that emerge when using constant parameter OLS approaches where economically non-constant betas must be expected. Compared to previous approaches trying to account for non-constant betas or correlations using rolling window regressions like, e.g., Bessler and Kurmann (2014), our estimations using Kalman filter produce distinctively lower estimation errors and thus facilitate timelier and more precise reactions to systemic threats.

We analyze the dynamics of the banking system's risk exposures with regard to their magnitude and time structure as well as with regard to relationships with the macroeconomic environment and the structure of the banking system. The banking system's mean *MR* beta is close to (but statistically different from) one as expected. The mean *IRR* beta is close to (but statistically different from) zero which is the value implied by the bank hedging literature that argues the elimination of easily hedgeable systematic risks to be the optimal risk policy (e.g., Diamond and Dybvig 1983; Froot and Stein 1998). Over time, there is substantial variation of both risk exposures with *MR* (*IRR*) ranging from 0.42 (−0.62) at the 1 % percentile to 2.98 (0.65) at the 99 % percentile. The dynamics of both risks are visually related to different cycles of the macro economy. This is consistent with, e.g., Hellwig (1994, 1998) and Hanson et al. (2015), who recognize and rationalize risk-taking based on different grounds like moral hazard in the sharing of banks' risks that also fueled the extremely short-term refinancing of banks in the run-up to the financial crisis (e.g., Farhi and Tirole 2012; Brunnermeier and Oehmke 2013).

To explain the relation of the banking system's time-varying *MR* and *IRR* betas to the macro economy, we use a very broad set of 119 macroeconomic variables. However, to avoid multicollinearity and for parsimony of the models we follow Ludvigson and Ng (2009) based on Stock and Watson (2002) and distill the information contained in these variables to a set of 9 macro factors using factor analysis. These macro factors explain more than 60 % of the variance in the underlying macroeconomic variables and, more importantly, around 40 and 20 % of the time-variation in *MR* and *IRR* betas, respectively. The macro factors which are most strongly related to the banking system's *MR* and *IRR* betas represent economic output and employment, housing market conditions as well as term and credit spreads. In further analyses, we additionally relate the banking systems *MR* and *IRR* betas to variables describing the state and structure of the banking system itself. We find that the system's size, its leverage, the ratio of loans to total assets and loan growth are significantly related to the system's dynamic *MR* betas. *IRR* betas are significantly linked to the banking system's leverage.

In the second part of the paper we analyze the exposures of the banking system in more detail by estimating each bank's contribution to the system's *MR* and *IRR* betas as the change in the system's risk exposures assuming that the bank never existed. Here, we follow the approach of Hovakimian et al. (2012). Summary statistics of these contributions reveal that banks have non-trivial leverage over the banking system's systematic risk at specific times. Therefore, we relate the individual banks' systemic *MR* and *IRR* contributions to bank characteristics by estimating fixed effects panel models. For the *MR* contributions, loan to deposit ratio and maturity transformation intensity are the relevant banking characteristics. *IRR* is related to individual banks' financing or deposit base, maturity transformation intensity and interest income, earnings diversification and the liquidity of banks' holdings. This may help regulators when surveilling individual banks' *IRR* and *MR* and their respective impact on the risk exposures of the entire banking system.

Overall, our paper thus adds new dimensions to the analysis of banks' systematic *MR* and *IRR* dynamics. We show how exposures of the banking system to these risks change over time and how they are related to the macro economy as well as to the structure of the banking system itself. Finally, we measure which bank characteristics are related to individual banks' contributions to the system's *MR* and *IRR* betas. Our findings allow regulators and investors a better understanding of the interdependency of the banking system and the macro economy at both the system and individual bank levels and facilitate better oversight and risk management. Our results are robust to specific tests using different interest rates as *IRR* factors and controlling for further systematic risks like credit risk and foreign exchange risk.

2 Data

Our sample consists of exchange traded US BHCs filing quarterly FR Y-9C reports with the Board of Governors of the Federal Reserve System (FED). Additionally, we aggregate subsidiary data like, e.g., type and maturity of deposits contained in the Call Reports, available via the Chicago FED and the Federal Deposit Insurance Corporation (FDIC), by summing across the commercial bank subsidiaries of each BHC.[2] Similar data on US banks are used by, e.g., Zagonov (2011), English et al. (2012) and Brunnermeier et al. (2012). Return data for these banks and a value-weighted US total market index (*MR*) are obtained from Thomson Reuters Datastream.[3] Information on government bond interest rates (*IRR*) from Gurkaynak et al. (2007) is made available via the FED.

We obtain macroeconomic variables from the Federal Reserve Economic Database (FRED). Similar variables are used by, e.g., Ludvigson and Ng (2009) based on Stock and Watson (2002). Like in these papers, variables are chosen to reflect broad categories of the overall economy. The list of variables is shown in "Appendix 1" including the type of transformation applied to ensure stationarity. As in Ludvigson and Ng (2009), we include financial variables in this list because cycles in the economy are determined to a large degree by co-movement of financial and real economic variables.

Banking system specific variables are obtained from the weekly H.8 release by the FED and represent assets and liabilities of domestically chartered US

---

[2] We follow, e.g., Kashyap et al. (2002), acknowledging the same biases in these variables (like double counting of inter-subsidiary business or the omission of non-bank activities).

[3] We follow the standard approach to screening the Thomson/Reuters Datastream return data introduced by Ince and Porter (2006).

commercial banks. To achieve consistency with macro variables from FRED, bank system variables are used in their seasonally-adjusted (*sa*) form. Many of the 53 seasonally-adjusted (*sa*) variables reported in the H.8 release are overlapping with regard to economic or informational content (like different liquidity definitions or shares of loan segments). Therefore, we focus on a number of core variables capturing economic information on size, financing structure, asset composition and loan growth rate without inducing multicollinearity in the analyses.

We restrict our analysis to domestic banks with charter type BHC. To ensure consistent time-series, we drop lower-tier BHCs (defined as being owned by another BHC by more than 50 % of equity) and BHCs with total consolidated assets of less than $500 million (in 2006:Q1 dollar terms).[4] This results in an unbalanced panel of 333 unique BHCs. This is in line with recent studies that also combine regulatory data on the BHC (and commercial bank) level with market data on these banks, like, e.g., Zagonov (2011), English et al. (2012) and Brunnermeier et al. (2012). The sample period lasts from 07/1997 to 12/2012, with the main restricting factor being the availability of data on maturities of deposits and savings deposits in the H.8 release.

Overall, our BHC sample strongly resembles the characteristics of the entire commercial banking system. On average, our sample includes more than 80 % of commercial banks' aggregate total assets as reported in the FED's H.8 release. Time-series descriptive statistics of total assets-weighted balance sheet ratios of banks in our sample are similar to ratios calculated from the H.8 release of the entire US commercial banking system. Deviations below 10 pp, e.g., for the reliance on deposit finance or the share of total loans to total assets resemble the greater size of BHCs compared to smaller commercial banks not included in our sample. Time-series correlations of respective ratios exceed 80 % (for the loans-to-assets ratio the correlation is above 60 %).

3 Time-varying *MR* and *IRR* betas of the US banking system

3.1 Estimation methodology using Kalman filter

Earlier research, like, e.g., Kane and Unal (1988, 1990) and Jagannathan and Wang (1996), already point in the direction of modeling time-dependency of systematic risks. Recent applications like, e.g., Patton and Verardo (2012) show the validity of such approaches. Especially the theoretical argument made by Elliott and Müller (2006) is convincing that a constant parameter, like an OLS coefficients, has no interpretation when the true marginal effect can be assumed to be time-dependent. Single banks' and therefore the entire banking system's portfolio are permanently undergoing changes in composition on both the asset and liability side for various

[4] See Micro Report Series Description, http://www.federalreserve.gov/reportforms/mdrm/pdf/BHCF.PDF "Beginning March 31, 2006, the FR Y-9C and the FR Y-9LP filing threshold was increased from $150 million to $500 million or more and the reporting exception that required each lower-tier bank holding company with total consolidated assets of $1 billion or more to file the FR Y-9C was eliminated.".

reasons. The most prominent among them being changes in supply and demand of capital and related prices, changing expectations with regard to risk and returns and—having become more and more binding and frequent—changes in regulatory requirements.

Therefore, this section analyzes how the *IRR* and *MR* exposures of the system of US BHCs have developed over time. Based on the unconditional two-factor models used by Stone (1974) and Flannery and James (1984), we methodologically follow Entrop et al. (2016) and set up the following state space model to estimate time-varying *IRR* and *MR* betas from weekly market value-weighted BHC system portfolio returns. The state space model is characterized by Eqs. (1) and (2):

$$r_{SYS,s} = \alpha_{SYS} + \beta_{SYS,MR,s} r_{M,s} + \beta_{SYS,IRR,s} r_{IR,s} + \sigma_{r_{SYS}} \in_{SYS,s}, \tag{1}$$

$$\begin{bmatrix} \beta_{SYS,MR,s+1} \\ \beta_{SYS,IRR,s+1} \end{bmatrix} = \begin{bmatrix} \beta_{SYS,MR,s} \\ \beta_{SYS,IRR,s} \end{bmatrix} + \begin{bmatrix} \sigma_{SYS,MR} & 0 \\ 0 & \sigma_{SYS,IRR} \end{bmatrix} \eta_{SYS,s}, \tag{2}$$

where $r_{SYS,s}$ is the BHC system's total portfolio return, $r_{M,s}$ is the total return of the Datastream value-weighted US total market index and $r_{IR,s}$ is the relative change of the US 10-year government bond spot rate in week s.[5] $\in_{SYS,s}$ are independently and standard normally distributed measurement errors. Transition equations for the unobserved states conditional on week s, $\beta_{SYS,MR,s}$ and $\beta_{SYS,IRR,s}$, are modeled as a random walk and estimated via Kalman filtering with diffuse initialization of the initial states.[6] $\eta_{SYS,s}$ represents a vector of two independent disturbances that are independently and standard normally distributed. $\in_{SYS,s}$ and $\eta_{SYS,s}$ are uncorrelated at all times. The hyperparameters α_{SYS} and $\sigma_{r_{SYS}}$ as well as $\sigma_{SYS,MR}$ and $\sigma_{SYS,IRR}$, respectively, constitute the time-invariant constant of the return regression in Eq. (1) and scale the variances of the error terms, respectively. They are estimated using maximum likelihood (functional restrictions are applied to avoid negativity for the variance scaling hyperparameters).

In our modeling setup, states $\beta_{SYS,MR,s}$ and $\beta_{SYS,IRR,s}$ estimated using the Kalman filter represent the sensitivity of the banking system portfolio's return in week s to the market and interest rate factor, respectively. Studies in other finance areas like Mamaysky et al. (2008), Mergner and Bulla (2008) and Choudhry and Wu (2008) have shown this choice of model to be the most efficient. Robustness of the results presented below with regard to the measurement error of *IRR* and *MR* betas is ensured, as the RMSE of the two-factor state space model measurement equation Eq. (1) is 22.9 % (19.8 %) lower than that resulting from an alternatively conducted OLS rolling window two-factor model of Eq. (1) with overlapping 5-year (1-year) estimation windows.

[5] Under this definition of the interest rate factor negative IRR betas indicate a negative bank portfolio stock return for increases in interest rates.

[6] The first 355 states estimated on return data available before the sample period are used to allow for enough time for the diffuse initialization but are dropped from further analyses also due to the constrained availability of macro and banking variables.

3.2 Summary statistics on time-varying *MR* and *IRR* betas

Using the results from the Kalman filter estimation we are the first to show how *IRR* and *MR* betas of the system of US BHCs developed over our sample period and to what extent they are in accordance with classic bank hedging theory. Table 1 shows summary statistics of time-series of *MR* and *IRR* betas for the US banking system from 07/1997 to 12/2012 estimated from the state space system characterized by Eqs. (1) and (2).[7]

The mean *MR* beta of the banking system is slightly above (but statistically different from) one with a value of 1.147; the median is 1.077. This is consistent with the expectation that the banking system represents a diversified portfolio of exposures to banks' corporate customers and that, consequentially, bank stock returns tend to be mostly aligned with the broad market index but exhibit stronger fluctuations. The high standard deviation of 0.421 shows strongly fluctuating banking system *MR* betas over time. Looking at the tails of the *MR* beta distribution reveals that there are phases where the BHC system co-moves only moderately with the stock market, while there are also periods with significantly stronger reactions of banks' stock returns to overall market movements. The distribution is positively skewed and shows excess kurtosis in comparison with a normal distribution.

The mean *IRR* beta of the banking system is slightly negative with a (statistically significant) value of −0.043; the median is −0.029. The magnitude of the mean *IRR* beta does not exhibit strong economic significance: a one standard deviation shock of relative changes in the 10-year spot rates indicates an annualized return for the average *IRR* beta of around −1.1 % during the sample period. This low average impact of IRR on the banking system's return is consistent with the bank hedging literature which argues that the elimination of easily hedgeable systematic risks is the optimal risk policy to be followed by banks (e.g., Diamond and Dybvig 1983; Froot and Stein 1998).

Moreover, the betas close to zero are consistent with interpreting the interest rate factor as the maturity transformation "style" of the bank. The slightly negative mean and median *IRR* betas thus indicate that the BHC system's equity value decreases when interest rates rise, which is the case when banks perform positive term transformation, i.e., financing long-term loans with short-term liabilities. However, the tails of the *IRR* beta distribution and the standard deviation of 0.207 reveal significant variation over time. In contrast to the *MR* beta distribution, the *IRR* beta distribution is almost symmetric and exhibits lower excess kurtosis.

Figure 1 shows the development of the BHC system's *MR* and *IRR* betas over time. The time-series of *MR* betas shows that the BHC system mostly co-moves closely with the market, most of the time with higher volatility than the market itself. There are phases where this relationship breaks down or is weakened. One

[7] As each month's last weekly beta is later matched to end-of-month macro variables, we already present results and base the following arguments on each month's last weekly betas to conserve space. As expected from a measure without unit like a regression coefficient, distributions of betas at the weekly frequency are highly similar and this approach does not change conclusions drawn in this section. Descriptive statistics of *IRR* betas at the weekly frequency can be obtained from the authors on request.

Table 1 Time-series summary statistics of the banking system's *MR* and *IRR* betas

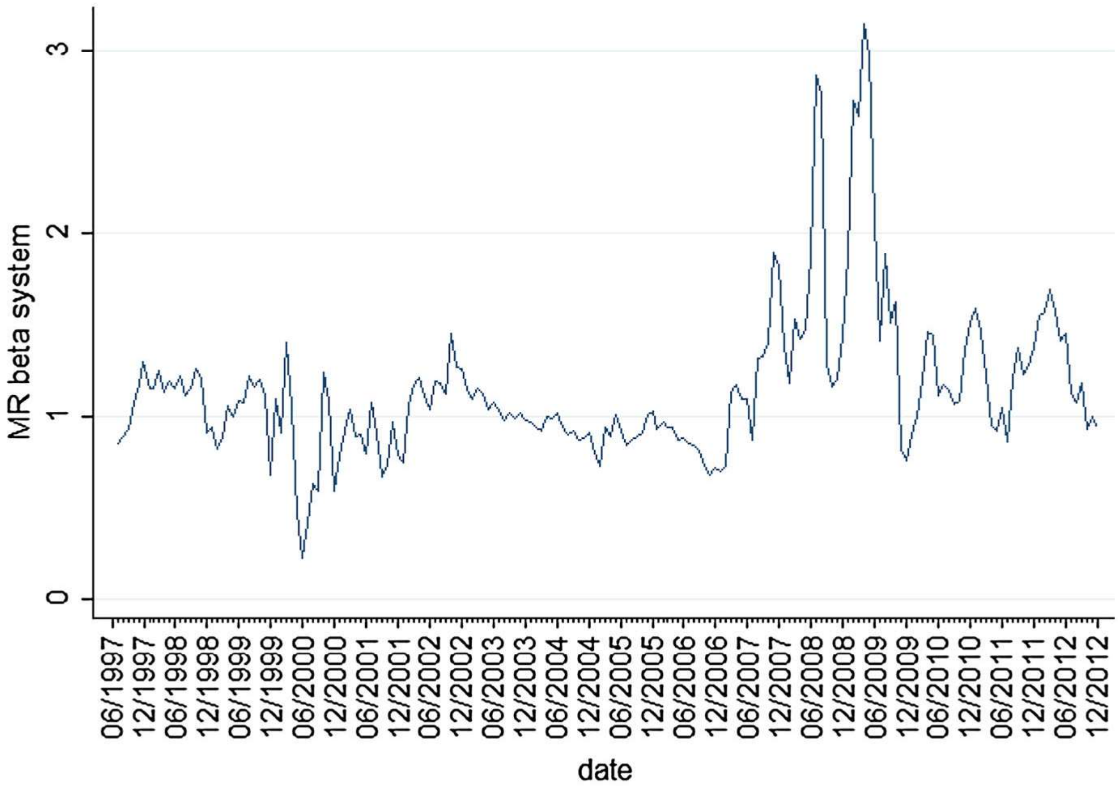
	Percentiles					Mean	Standard deviation
	1 %	10 %	50 %	90 %	99 %		
MR	0.419	0.785	1.077	1.527	2.980	1.147	0.421
IRR	−0.620	−0.314	−0.029	0.180	0.652	−0.043	0.207

This table shows summary statistics of monthly time-series of *MR* and *IRR* betas for the US BHC system from 07/1997 to 12/2012 estimated from the two-factor state space systems characterized by Eqs. (1) and (2)

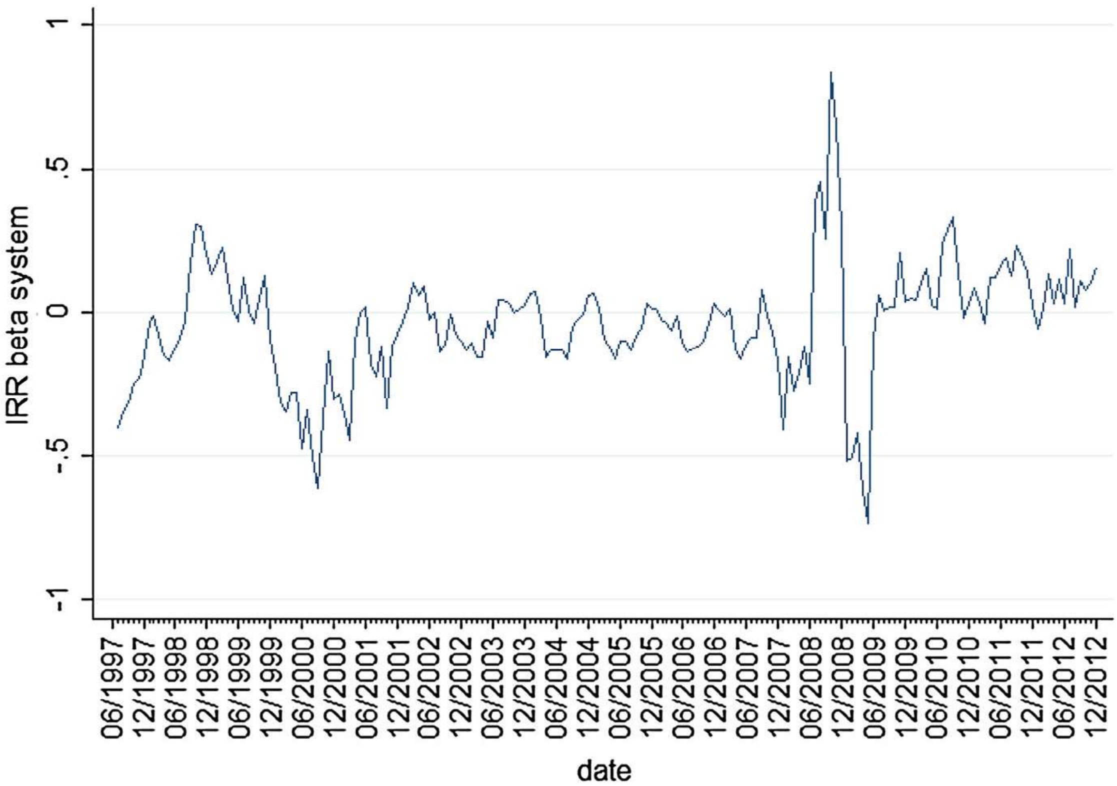
example is the time of the internet bubble. Here, the BHC system is to some degree decoupled from the market. This regime ends after the burst of the internet bubble and 9/11 and the succeeding economic contraction. The degree and strength of the co-movement is again slowly weakening hereafter until the first indications of the upcoming financial crisis in 2007. During the financial crisis and until the end of our sample period we see an increase in *MR* betas resulting from extreme movements of market prices of banks' equity. *MR* betas remain at a level well above one until the end of our sample period.

IRR betas of the BHC system are fluctuating slightly below or around zero over much of the sample period, indicating no or negative exposure to rising interest rates, consistent with rather positive than negative term transformation. From the beginning of the sample period until mid-1998 and during the times of the internet bubble we do see a higher degree of negative exposure to rising interest rates. From 2004 to 2007 there seems to be a seasonal pattern of *IRR* betas with year-end values being close to 0 while during the year *IRR* betas are mostly negative around values of −0.1. This pattern breaks down in the third quarter of 2007, where we see an increase to values above 0 before there is again a drop that this time lasts over the year-end until mid-2008.

The most conspicuous pattern of the banking system's *IRR* beta is a sharp increase to 0.8 at the end of October 2008 followed by a sharp drop in the opposite direction to values well below 0. This may be explained by the US real estate crisis and the bankruptcy of Lehman Brothers which led the FED to very sharp decreases of the federal funds rate to almost zero by the end of 2008. In the short term, this increased banks' interest margins and went along with partially restored trust and thus rising stock prices in the third quarter of 2008. Overall, however, it led also to an extremely uncertain and illiquid environment on the refinancing market in which banks' and investors' adjustments to the new situation might have been hyperbolized. The partially restored trust in the banking system was finally destroyed by the bankruptcy of Lehman Brothers at the end of September 2008, as now investors finally realized the build-up of excessive short-term financing and related term transformations (see, e.g., Brunnermeier and Oehmke 2013; Hoerdahl and King 2008; Gorton and Metrick 2012). The following measures taken by the FED gradually restored trust and led the market to return to a more normal state,



Panel a



Panel b

Fig. 1 **a** (**b**) of this figure shows the development of the BHC system's *MR* beta (*IRR* beta) over time in the period from 07/1997 to 12/2012 estimated using the two-factor state space system characterized by Eqs. (1) and (2) until the end of our sample period, the *IRR* exposures are mostly fluctuating in the positive value range.

4 Explaining the time-varying *MR* and *IRR* exposures of the BHC system

4.1 Relation between *MR* and *IRR* betas and the macro economy

After showing that there is significant variation of the banking system's *MR* and *IRR* betas over time and that the dynamics of both exposures can be visually related to overall market movements, this section investigates how the macro economy influences such dynamics. Therefore, we refer to Ludvigson and Ng (2009) who investigate the determinants of bond market premiums and follow their argument that the important consideration is not which individual macroeconomic variables are used but that the estimated macro factors derived from the variables are highly representative of economic activity. Following their approach we apply a factor representation of a broad set of 119 macroeconomic variables from the FRED database to explain variation in the BHC system's *MR* and *IRR* betas.[8] Factor analysis on the transformed macroeconomic variables lead to a factor structure for which the first 9 factors explain more than 60 % of the variance of all 119 variables employed.[9] We apply the orthogonal varimax rotation (Kaiser 1958) on the factor structure to arrive at our final set of nine standardized uncorrelated macroeconomic factors, $FFF1$–$FFF9$.

Table 2 shows results from regressions, Eqs. (3) and (4), of the monthly (t) time-series of the BHC system's *MR* and *IRR* betas from 07/1997 to 12/2012 on the 9 macro factors. To control for endogeneity and reverse causality in the relations we use one month lagged independent variables.[10] Overall, the factors explain almost 40 % of the variation in the BHC system's *MR* beta and 20 % of the variation in the BHC system's *IRR* beta. This shows that the overall macroeconomic environment has a strong impact on the banking system's systematic risk exposures.

$$\beta_{SYS_{,MR,t}} = \theta_{SYS,MR,0} + \sum_{m=1}^{9} \theta_{SYS,MR,m}\, macro\,factor_{m,t-1} + v_{SYS,MR,t} \qquad (3)$$

[8] Variables 1–19 describe output with production in different sectors, variables 20–44 employment and working hours, variables 45–54 contain information on the stock of orders, 55–64 housing including prices and starts of construction, 65–87 describe the financial environment including stock market, interest rates and spreads and exchange rates, 88–94 describe the monetary policy with monetary bases and reserve requirements, and 95–119 describe prices for producers and consumers. For detailed definitions of the numbered macroeconomic variables (most of them on a seasonally-adjusted basis) and of the transformations applied to ensure stationarity, see Appendix 1.

[9] Visual inspection of the scree plot leads to the decision for the cutoff at nine factors, as additional factors add substantially less marginal explanatory power to the factor structure.

[10] We use lagged rather than contemporary independent variables to control for endogeneity and reverse causality of the relations.

Table 2 Regressions of *MR* and *IRR* betas on macro factors

	MR		*IRR*	
	Coefficient	Standard error	Coefficient	Standard error
*FFF*1	−0.140***	0.036	0.029	0.021
*FFF*2	−0.193***	0.025	−0.056***	0.014
*FFF*3	0.015	0.023	−0.014	0.014
*FFF*4	−0.025	0.022	−0.004	0.024
*FFF*5	0.025	0.021	0.040***	0.014
*FFF*6	0.050	0.031	−0.022	0.019
*FFF*7	−0.017	0.025	0.028	0.018
*FFF*8	0.004	0.027	−0.009	0.024
*FFF*9	−0.058*	0.033	0.032	0.020
Intercept	1.132***	0.024	−0.035**	0.014
R^2	0.396		0.200	

This table shows results from regressions, Eqs. (3) and (4), of the monthly time-series of the BHC system's *MR* and *IRR* betas from 07/1997 to 12/2012 on one month lagged macro factors. The 9 macro factors result from a varimax rotation of a factor representation of 119 macroeconomic variables obtained from the FRED database. Standard errors are clustered at the time dimension. ***, **, and * indicate significance at the 1, 5, and 10 % levels, respectively

$$\beta_{SYS_{,IRR,t}} = \theta_{SYS,IRR,0} + \sum_{m=1}^{9} \theta_{SYS,IRR,m}\, macrofactor_{m,t-1} + v_{SYS,IRR,t} \tag{4}$$

For each of the systematic exposures of the BHC system, two macro factors show significant coefficients at the 5 % level. *MR* beta is significantly linked to *FFF*1 and *FFF*2, whereas *IRR* beta is significantly linked to *FFF*2 and *FFF*5. To get an understanding of what macroeconomic categories are described by these factors, we include Fig. 2 that shows the marginal R^2 for the three relevant macro factors, *FFF*1, *FFF*2 and *FFF*5, in regressions of the respective macro factor on each of the 119 macroeconomic variables. *FFF*1 is most strongly related to output and employment, especially to the manufacturing production and employment index, to average weekly hours of production and non-supervisory employees in that sector, and to overall (un)employment; to some lower degree it is related to short-term interest rates. *FFF*2 can be seen as an almost pure housing factor being related almost perfectly to housing prices and number of permits for new housing (and to the producer price index for commodities). *FFF*5 is strongly related to term and credit spreads above the federal funds rate.

For further insight regarding the direction and dynamics of the macro factors and thus the interpretations of the coefficients in Table 2; Fig. 3 shows the time-series plots of the three relevant macro factors, *FFF*1 (output and employment), *FFF*2 (housing) and *FFF*5 (term and credit spreads). Consistent with economic intuition, the most noticeable events in output and employment take place around the burst of the internet bubble and 9/11 and especially around the financial crisis. Housing is

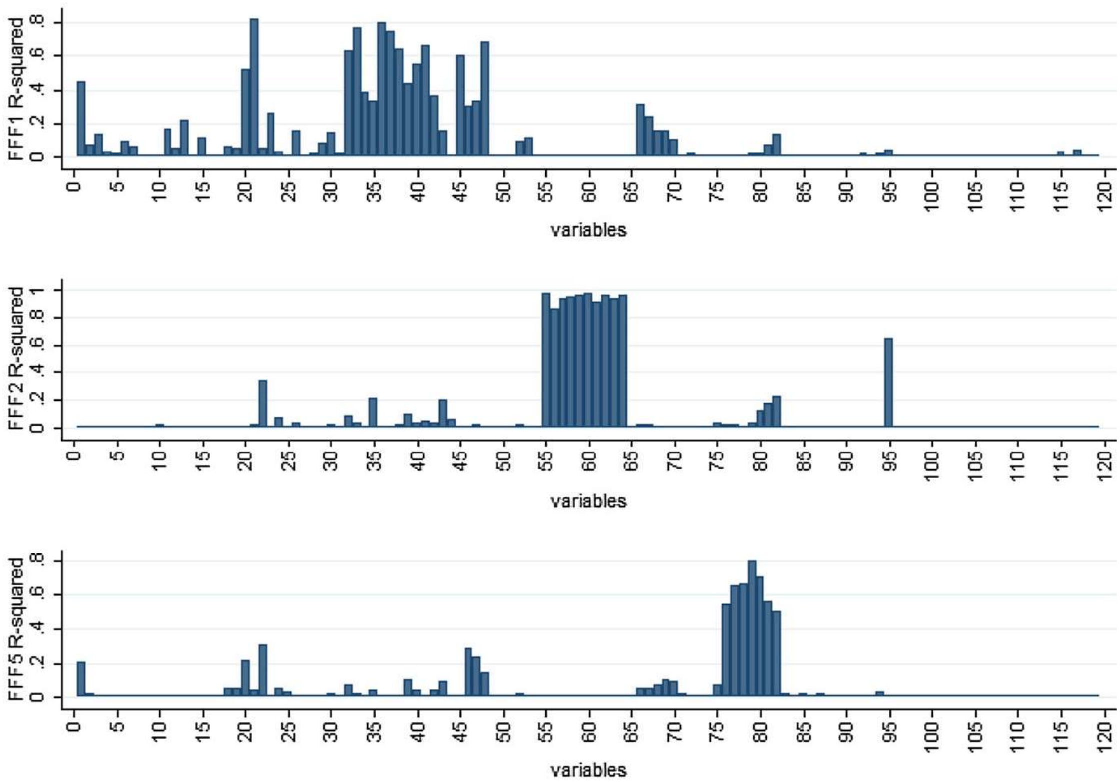


Fig. 2 This figure shows the marginal R^2 for the three relevant macro factors, *FFF*1, *FFF*2 and *FFF*5, when regressing each macroeconomic variable on the respective macro factor. See "Appendix 1" for a list and description of the 119 macroeconomic variables

very stable on a high level until the first foreshadows of the subprime mortgage crisis become evident mid-2006 and afterwards declines to a new, lower but also relatively stable level until the end of the sample period. Credit and term spreads are the most volatile of the three macro factors, with noticeable increases after the internet bubble burst and after the striking events of the financial crisis.

Looking specifically at the coefficients on the three macro factors in Table 2, the banking system's *MR* beta is negatively related to *FFF*1 which means lower *MR* betas in phases of high output and employment. This indicates a weakened co-movement of the banking system's valuations with the equity market during phases of an expansion of the real economy. On the other hand, banks become closer connected to the market or even exceed market movements during contractions of the real economy. One can see the strong procyclicality of both banks' business and the related regulatory environment as an explanation. The latter is forcing banks to substantially scale down their activities during economic contractions, as has been the case in the last financial crisis. This again leads to a stronger connection to the market during time of crises. This relationship can be viewed as a banking-specific, regulatory-driven version of the leverage effect that is used to explain the asymmetric link between stock returns and their volatility (clustering). This analogy is emphasized due to the high leverage generally employed by banks.

Both the *MR* and *IRR* betas are negatively related to *FFF*2 which means that the banking system's betas are lower if the housing business is high. Regarding *MR*, this can be explained with real estate being the most important collateral underlying

Fig. 3 This figure shows time-series plots of the three relevant macro factors, *FFF*1, *FFF*2 and *FFF*5, over time in the period from 07/1997 to 12/2012

banking loans. This means that with decreases in housing prices, as could be seen especially during the last financial crisis, the value of banks' collateral decreases forcing them again to deleverage their balance sheets accepting losses above the overall market level of losses.

Regarding *IRR* beta, the negative relation can be explained by banks' binding regulatory framework and possible gains from coordinated risk management as in Schrand and Unal (1998): banks facing the choice between taking on core business risk—i.e., credit risk that allows them to earn rents from informational advantages from customer screening and monitoring—and taking on homogenous risk—i.e., from a source of risk considered observable by all market participants with little chance of achieving a risk-adjusted excess return—may opt for the first kind of risk, when increases in total risk are costly. This way, decreasing housing prices reduce the value of collateral making risk capital scarcer. This leads to shift away from negative *IRR* and related positive term transformation. In contrast, increases in housing prices makes banks' collateral safer, releases risk capital and thus allows to take on more negative *IRR*, e.g., from positive term transformation. This might make sense especially when risk premiums on the credit market are decreasing due to the overall increase in available risk capital.

The positive relationship of *FFF*5 and the *IRR* beta points in a similar direction: *FFF*5 is strongly related to term and credit spreads above the federal funds rate. Higher term and credit spreads on the capital markets pose increased opportunity costs for banks' customers, making banks' products for which pricing includes market rates and a margin—to some degree fixed to cover fixed-costs—more attractive. Higher term and credit spreads thus allow banks to gain higher margins from their business, as they are relatively lower compared to market rates and thus more easy to "sell" to customers. This, in turn, reduces the tendency or even need (in terms of gamble for resurrection or go-for-broke strategies[11]) for banks to take on negative *IRR* from positive term transformation. This leads to a positive association of macro factor *FFF*5 with *IRR* betas.

4.2 Relation between *MR* and *IRR* betas and the structure of the banking system

In this section, to analyze if—besides macroeconomic influences—also the overall structure or state of the banking system itself influence the dynamics of the systems *MR* and *IRR* betas, we use variables from the H.8 report as explanatory variables. Therefore, we aggregate weekly data to end-of-the-month data and use 7 seasonally-adjusted (*sa*) variables which are chosen from the set of 53 variables for parsimony and to reduce multicollinearity. *SIZEsa* is the natural logarithm of CPI-adjusted total assets (in terms of 01/2009 dollars). *LEVsa* is the ratio of total assets to book value of equity. *SavD/TLisa* describes the ratio of savings deposits to total liabilities. *TL/TAsa*, *TCI/TLsa* and *Lgrowsa* represent the share of total loans to total assets, the share of commercial and industrial loans to total loans and the monthly log growth rate of total loans, respectivly. *LIQGsa* is the ratio of cash and government and agency securities to total assets. Again, we use one month lagged variables to control for endogeneity and reverse causality in the relations.

Table 3 shows the results of time series regressions analog to Table 2 but replacing the 9 lagged macro factors in Eqs. (3) and (4) with the 7 lagged banking system variables. Overall, the regressions show a good fit with R^2 of over 30 % for the *MR* beta and over 21 % for the *IRR* beta. *SIZEsa*, *LEVsa*, and *TL/TAsa* are positively linked to *MR* beta above the 5 % significance level. This can be explained, as the banking sector's increase in size both in absolute terms and relative to the overall economy leads to a stronger connection to the overall market. The same effect is to be expected for greater leverage. As *MR* is viewed here from an equity holder's perspective, greater leverage is associated with stronger dependence on the overall market development. Moreover, this could be related to the usual increase of the levered beta (as opposed to the unlevered beta) with increasing leverage. Similarly, greater dependence on the market is also to be expected for times with a greater share of loans to total assets. If banks are invested directly in the economy to a greater degree, as expressed by greater *TL/TAsa*, banks' *MR* exposure is deemed to be higher.

The opposite relationship is found for *Lgrowsa* which shows a negative and statistically significant coefficient. This can be explained with higher *Lgrowsa* being a sign of greater supply and/or demand for loans. During such times there are plenty

[11] See, e.g., Marcus (1984) or Dewatripont and Tirole (1994) for analyses of the behavior of banks that have lost the basis for successful continuation of their business models.

Table 3 Regressions of *MR* and *IRR* betas on banking system variables

	MR		*IRR*	
	Coefficient	Standard error	Coefficient	Standard error
SIZEsa	3.198***	0.840	−0.625	0.446
LEV sa	0.267**	0.121	−0.169***	0.057
SavD/TLisa	−4.607	6.138	−1.978	2.714
TL/TAsa	16.277***	4.860	−3.268	2.543
TCI/TLsa	1.863	1.741	0.416	1.161
Lgrowsa	−11.870**	4.732	3.662	3.291
LIQGsa	11.084*	6.010	−2.672	2.627
Intercept	−108.746	29.482	22.796	15.266
R^2	0.302		0.217	
R^2 incl. *FFFs*	0.462		0.346	

This table shows results from regressions, Eqs. (3) and (4), of the monthly time series of the BHC system's *MR* and *IRR* betas from 07/1997 to 12/2012 on one month lagged banking system variables. The last row shows R^2s from regressions using banking system variables and macro factors. Standard errors are clustered at the time dimension. ***, **, and * indicate significance at the 1, 5, and 10 % levels, respectively

of investment opportunities for banks allowing them in some respect to pick and choose exposures that fit their risk appetite. In the same regard, they might be able to enforce higher margins, stricter covenants and better collateralization that shield them against risks of the overall economy.

Regarding the dynamic of *IRR* beta, although the banking system variables employed show a high overall explanatory power, it is only linked significantly to the banking system's lagged leverage, *LEVsa*. This shows that with increasing leverage the *IRR* beta tends to become more negative. Similar to the argument made above for *MR*, greater leverage means greater exposure to systematic risks, as levered beta (contrary to unlevered beta) increases with leverage. With regard to *IRR* we do see an on average negative *IRR* beta from on average positive term transformation. In such a strategic position, higher leverage increases the relative importance of the term transformation margin with regard to bank's overall absolute profits and value of equity. If interest rates increase in such a situation, the term transformation margin decreases more strongly leading to lower bank stock returns.

Concluding this section, we test if explanatory power of the dynamics in the banking system's *MR* and *IRR* betas is improved when adding the banking system variables used in this sub-section to the macro factors *FFF*1 – *FFF*9 used in sub-Sect. 4.1. Therefore, the last row of Table 3 shows the R^2 of regressions with all 16 factors as explanatory variables. Compared with Table 2 (the top section of Table 3), we do see an increase in R^2 for *MR* beta models from 0.396 (0.302) to 0.462, whereas for the *IRR* beta the increase in R^2 is even stronger from 0.200 (0.217) to 0.346. Although R^2 from combining both sets of explanatory variables in the last row of Table 3 are significantly lower than the sums of R^2 when including only one set of explanatory variables indicates the presence of strong correlations, the state of the system drives the risk dynamics of the banking system's systematic risks to some degree beyond macroeconomic variables. This result is confirmed as likelihood ratio tests show that for both exposures the addition of the H.8 variables significantly adds explanatory power, as the block of H.8 variables is jointly statistically significant. They should thus be considered by regulators and investors as an approximation of the state of the overall banking system.

5 Sensitivity of the banking system's *MR* and *IRR* betas to banks' risk contributions

5.1 Measures of banks' contributions to the system's *MR* and *IRR* betas and statistics on bank characteristics

To further explore the roots of the BHC system's systematic risk exposures, this section analyzes the sensitivity of the banking system's *MR* and *IRR* betas to the risk contributions of single banks. To measure single banks' risk contributions, we follow an approach by Hovakimian et al. (2012) who measure each bank's contribution to the credit risk of the overall US banking sector based on the Merton (1977) structural model of deposit insurance benefits. Similarly, we apply the state space system defined in Eqs. (1) and (2) using the Kalman filter for each bank $b = 1,\ldots, B$ on the weekly market value-weighted portfolio return of the BHC system but excluding bank b from the portfolio, $r_{SYS-b,s}$. Thus, we arrive at weekly *MR* and *IRR* betas $\beta_{SYS\text{-}b,MR,s}$ and $\beta_{SYS-b,IRR,s}$ which can be interpreted as the systematic exposures of the banking system to *MR* and *IRR* assuming that bank b never existed. As described by Eqs. (5) and (6), we subtract these exposures from the overall banking system's exposures from Sect. 3. This yields each bank b's weekly contributions to the banking system's systematic *MR*, $\beta^{\Delta}_{b,MR,s}$, and to the system's *IRR*, $\beta^{\Delta}_{b,IRR,s}$, respectively.

$$\beta^{\Delta}_{b,MR,s} = \beta_{SYS,MR,s} - \beta_{SYS-b,MR,s} \tag{5}$$

$$\beta^{\Delta}_{b,IRR,s} = \beta_{SYS,IRR,s} - \beta_{SYS-b,IRR,s} \tag{6}$$

We then aggregate these weekly risk contributions to quarters q[12] and match the resulting quarterly risk contributions to one quarter lagged bank characteristics consisting of on- and off-balance sheet data from quarterly regulatory reports. Following Whited and Wu (2006) we require individual banks' continuous time-series of matched FR Y-9C, Call Report and *MR*/*IRR* exposures to cover at least eight quarters. This procedure results in an unbalanced panel of 11,576 quarterly

[12] According to the procedure for monthly aggregation described in Footnote 7 in Sect. 3.2 thereby following Brunnermeier et al. (2012).

observations of 333 unique banks. The average time span covered by a bank is 34.8 quarters. In each quarter we observe 187.5 banks on average. This is in line with recent studies that also combine regulatory data on the BHC (and commercial bank) level with market data on these banks (e.g., Zagonov 2011; English et al. 2012; Brunnermeier et al. 2012).

Panel A of Table 4 shows pooled summary statistics of quarterly *MR* and *IRR* beta contributions. As expected from their construction, mean and median risk contributions are close to zero. However, the respective standard deviations and percentile values of risk contributions indicate that some banks have non-trivial leverage on the systematic risk of the banking system at specific times. Specifically, looking at the 1 % (99 %) percentiles, single banks may increase (decrease) the system's *MR* beta by as much as 0.243 (−0.286) in single quarters. Similarly, single banks may increase (decrease) the system's *IRR* beta by as much as 0.183 (−0.306) in certain quarters. Hence, it is important to analyze which bank characteristics drive single bank's risk contributions to the BHC system's overall systematic risk.

From the regulatory reports, we use 13 bank characteristics to broadly cover banks business models as well as their risk management and strategy for similar reasons as laid out in related papers like, e.g., Zagonov (2011), English et al. (2012), Brunnermeier et al. (2012) and Entrop et al. (2016). The bank characteristics cover: log gross total assets (*SIZE*), financial leverage (*LEV*), demand and transaction deposits to total liabilities (*DTrD/TLi*), return on assets (*RoA*), net interest margin to total assets (*NIM*), total commercial and industrial loans to total loans (*TCI/TL*), total loans to total deposits (*TL/TD*), the growth rate of the bank's loan portfolio (*Lgrow*), a Herfindahl–Hirschman Index measuring loan segment diversification (*loanHHI*), maturity gap (*ALMM*, see English et al. 2012), non-performing loans to total assets (*NPL*), a Herfindahl–Hirschman Index variation measuring income diversification (*IncDiv*, see Laeven and Levine 2007; Zagonov 2011) and the ratio of liquid assets to total assets (*Liq*).

Summary statistics regarding the bank characteristics are presented in Panel B of Table 4. The average size of a bank is \$32.5 billion, median size is \$2.6 billion (in 2006:Q1 terms) which is why we use the natural logarithm of size in the further analyses to ensure stationarity. The ratio of total loans to total deposits, *TL/TD*, is quite symmetrically distributed with almost 75 % of observations showing a deposit base broad enough to finance outstanding loans. Demand and transaction deposits, *DTrD/TLi*, make up 13 % on average (11 % in median) of total liabilities. This is an indication of the prevalence of the classic commercial banking business model of deposit-financed loans in our sample. The maturity gap-measure, *ALMM*, is mostly positive with mean and median values around almost 4 years. It is below zero for 61 observations with the lowest values in the range of −20 months. This shows that positive term transformation is part of almost every bank's business model in the sample, although for a significant portion the extent of the maturity gap can be considered as being not excessive. Overall, these figures are in line with the related

Table 4 Pooled summary statistics of *MR* and *IRR* beta contributions and bank characteristics

	Percentiles					Mean	Standard deviation
	1 %	10 %	50 %	90 %	99 %		
Panel A bank's *MR* and *IRR* beta contributions							
$\beta^{\Delta}_{b,MR,q}$	−0.286	−0.061	0.000	0.026	0.243	−0.007	0.080
$\beta^{\Delta}_{b,IRR,q}$	−0.306	−0.028	0.000	0.028	0.183	−0.002	0.062
Panel B bank characteristics							
SIZE	20.162	20.674	21.708	24.273	27.756	22.129	1.507
LEV	5.646	8.293	11.291	15.485	22.46	11.743	10.311
DTrD/TLi	0.018	0.047	0.112	0.238	0.38	0.131	0.08
RoA	−0.031	0.001	0.005	0.012	0.02	0.005	0.009
NIM	0.005	0.008	0.02	0.036	0.047	0.021	0.011
TCI/TL	0.006	0.066	0.155	0.322	0.592	0.177	0.115
TL/TD	0.323	0.689	0.905	1.102	1.487	0.908	0.312
Lgrow	−0.085	−0.024	0.015	0.07	0.328	0.026	0.082
loanHHI	0.283	0.374	0.56	0.779	0.953	0.569	0.156
ALMM	0	21.02	43.142	77.302	104.902	46.362	22.317
NPL	0	0.001	0.005	0.027	0.067	0.01	0.014
IncDiv	0.024	0.146	0.324	0.639	0.946	0.362	0.212
LIQ	0.059	0.135	0.246	0.423	0.667	0.268	0.126

This table shows pooled summary statistics of the quarterly *MR* and *IRR* beta contributions determined using Eqs. (5) and (6) in Panel A, and bank characteristics in Panel B. For details on definition and construction of the bank characteristics, see "Appendix 2"

literature. For detailed information on definition, interpretation and construction of the bank characteristics, see "Appendix 2" and Entrop et al. (2016).

5.2 Explaining bank's contributions to the system's *MR* and *IRR* beta with bank characteristics

After showing descriptively that single banks may contribute non-trivially to the system's *MR* and *IRR* at specific times, it is important to analyze which bank characteristics may drive these contributions to give regulators and investors an idea of potential fulcrums for effective oversight and risk management. Therefore, we run panel regressions with bank-fixed effects of the quarterly *MR* and *IRR* beta contributions on the 13 lagged bank specific characteristics defined above and the 9 lagged macro factors defined in Sect. 4, *FFF*1–*FFF*9, to control for time-specific variations in the macroeconomic environment.[13]

[13] Multicollinearity is not an issue here, as shown by variance inflation factors (VIF): mean VIF of the variables is 1.45 with *NPL* exhibiting the highest value of 2.03.

$$\beta^{\Delta}_{b,MR,q} = \gamma_{b,MR,0} + \sum_{k=1}^{13} \gamma_{b,MR,k}\ bankcharacteristic_{k,b,q-1} + \sum_{m=14}^{22} \gamma_{MR,m}\ macrofactor_{m,q-1} + \varepsilon_{b,MR,q} \tag{7}$$

$$\beta^{\Delta}_{b,IRR,q} = \gamma_{b,IRR,0} + \sum_{k=1}^{13} \gamma_{b,IRR,k}\ bank\ characteristics_{k,b,q-1} + \sum_{m=14}^{22} \gamma_{IRR,m}\ macro\,factor_{m,q-1} + \varepsilon_{b,IRR,q} \tag{8}$$

The results are presented in Table 5 and indicate that both the *MR* and *IRR* beta contributions of single banks can be explained to some degree by bank characteristics and macro factors. The R^2 is above 8 % for *MR* beta contributions and almost 5 % for the *IRR* beta contributions; F-tests show that the explanatory variables are jointly significant. The magnitude of R^2 is similar to results in the related literature (see, e.g., English et al. 2012; Brunnermeier et al. 2012; Zagonov 2011).

MR beta contributions are related to only two of the 13 bank characteristics above the 5 % significance level. The positive sign of the ratio of total loans to total deposits (*TL/TD*) can be explained by banks originating loans beyond their deposit base exposing themselves increasingly to *MR*, as especially the asset side of the balance sheet—but also the liability side due to increased market financing needs—are more strongly connected with the overall development of the economy and the overall capital market. The negative relationship of the maturity gap (*ALMM*) with banks' *MR* beta contributions can be explained by a higher reliance on term transformation being related with less market risk. As term transformation results in *IRR* that is not perfectly correlated with the market [correlation of market and interest rate factors used for Eqs. (1) and (2) is 27 %], banks' regulatory cap on total risk might induce them to exchange *IRR* and credit risk or *MR* which can be seen as being partly responsible for the negative coefficient of *ALMM*.

IRR beta contributions are related to five bank characteristics above the 5 % significance level. The ratio of demand and transaction deposits to total liabilities (*DTrD/TLi*) is significantly positively associated with banks' *IRR* beta contributions. This indicates that banks that rely more on deposits as a source of financing add positively to the *IRR* beta of the BHC system. Economically this makes sense, as the slow and partly asymmetric interest rate pass-through for deposit accounts allows banks to decouple their financing costs from market rates; see, e.g., Gropp et al. (2007). Banks financed to a greater degree by deposits are thus less negatively affected by increases in interest rates. If a bank is able to raise deposits that represent net gains to the banking system by convincing customers that this form of investment is more attractive (in terms of safety, availability/immediacy or returns—also indirectly via stronger banking relationships) than investments outside

Table 5 Regressions of banks' *MR* and *IRR* beta contributions on bank characteristics

	MR		*IRR*	
	Coefficient	Standard error	Coefficient	Standard error
SIZE	0.0049	0.0031	0.0029	0.0036
LEV	0.0002	0.0002	0.0000	0.0001
DTrD/TLi	0.0103	0.0163	0.0412**	0.0181
RoA	−0.4727*	0.2685	0.0283	0.0716
NIM	0.0926	0.0873	−0.2735***	0.0480
TCI/TL	−0.0237	0.0222	−0.0506	0.0396
TL/TD	0.0189***	0.0065	−0.0061	0.0061
Lgrow	−0.0034	0.0084	−0.0165	0.0104
loanHHI	0.0109	0.0141	0.0102	0.0233
ALMM	−0.0002***	0.0001	−0.0002**	0.0001
NPL	−0.3043*	0.1718	0.2053	0.1253
IncDiv	−0.0041	0.0071	0.0193***	0.0065
LIQ	0.0003	0.0160	0.0493***	0.0164
Intercept	−0.1217	0.0664	−0.0726	0.0801
Macro factors	*Yes*		*Yes*	
Bank-fixed effects	*Yes*		*Yes*	
R^2	0.085		0.048	
Obs.	11,576		11,576	

This table shows results from panel regressions with bank-fixed effects, Eqs. (7) and (8), of banks' *MR* and *IRR* beta contributions on lagged bank characteristic. Macro factors $FFF1-FFF9$ are included to capture time-specific effects. Standard errors are clustered at the bank level. ***, **, and * indicate significance at the 1, 5, and 10 % levels, respectively

the banking sector, higher *DTrD/TLi* is associated with less negative *IRR* of the banking system.

Besides this effect, which is primarily driven by the liability side of a bank's balance sheet, we do find some relationships that are related to both sides, especially the variables related to term transformation, *NIM* and *ALMM*. Both are related negatively to *IRR* beta contributions; i.e., a higher net interest margin and a higher maturity gap are associated with lower (more negative) *IRR* beta contributions. This indicates that banks which generate higher profits with their interest-baring business (*NIM*), more positive term transformation (*ALMM*) and thus higher negative *IRR* betas make the BHC system more vulnerable to increases in interest rates.

Similarly, the significantly positive coefficients of *IncDiv* and *LIQ* with regard to the *IRR* beta contributions show that by diversifying risk or with the build-up of liquidity safety-cushions banks can reduce their *IRR*. A higher diversification of operating income by a bank—mostly away from traditional interest earning business to non-interest bearing business—(*IncDiv*) is associated with a shift of the banking system's *IRR* beta to more positive values when including this bank. The same effect can be shown for the extent of liquid holdings by a bank (*Liq*): higher liquidity buffers reduce the risk of not being able to cover payments that are coupled to market interest rates. This might especially be relevant in an environment that is characterized by rising interest rates.

Overall, we do find significant relationships between individual bank characteristics and their contributions to the banking system's systematic *MR* and *IRR* exposures. These findings allow us to get a better understanding of the origins of the banking system's overall risk exposures. Specifically, the banking system's *IRR* exposure as a whole is related to individual banks' financing or deposit base, maturity transformation intensity and interest income, earnings diversification and liquidity holdings via the inclusion of a bank in the system. For the *MR* exposure of the banking system the loan to deposit ratio and maturity transformation intensity are the relevant banking characteristics.

6 Robustness checks regarding factor and model choice

6.1 Measuring *IRR* beta using interest rates of different maturities

Throughout our empirical analysis, we use relative changes of the 10-year spot rate as interest rate factor for the estimation of *IRR* betas. However, previous studies like, e.g., Czaja et al. (2009) show that besides the interest rate level also other parameters of the yield curve like slope and curvature are important to determine bank's interest rate risk. On the other hand, studies like Litterman and Scheinkman (1991) argue that with around 90 %, almost all of the variation in interest rates can be traced to variation in the level alone. Thus, for model parsimony, we use only the level of long-term interest rates in our main analysis as argued by, e.g., Nelson and Siegel (1987).

To test the robustness of our results using the chosen 10-year spot rate as our single interest rate factor, we alternatively use the 7- and 5-year spot rates, respectively, for replications of the main results on the system level (Tables 2 and 3). As the results in both tables with both alternative interest rate factors are almost identical to those in our main analysis, we do not present the tables here but are happy to provide them upon request. With this test, we consider our results robust regarding the choice of the interest factor to measure the banking system's *IRR* betas.

6.2 Controlling for bank's other systematic risks

For our analysis of the dynamics of the banking system's *MR* and *IRR* betas we use the two-factor state space model defined in Eqs. (1) and (2) using Kalman filter. However, previous studies like, e.g., Bessler and Kurmann (2014) indicate that there exist other systematic risks determining banks' stock returns like credit risk, foreign exchange risk or real estate risk. Thus, not controlling for such risks in the estimation of the banking system's time-varying *MR* and *IRR* betas may induce an omitted variable bias, especially if *MR* and *IRR* are correlated with other risks.

Therefore, to test the robustness of our results using the two-factor state space model, we replicate our main empirical analysis on the system-level using *MR* and

IRR beta time-series calculated from three-factor state space models additionally including credit risk (*CR*) and foreign exchange risk (*FXR*), respectively. A first indication of the effects is given by Table 6. Panel A reports correlations between the four risk factors which are relatively low, especially between *IRR*, *CR* and *FXR*. Thus, the inclusion of the additional risk factors has no effect on the estimations of *MR* and *IRR* betas as shown by the correlations between *MR* (*IRR*) betas from different models in Panel B.

Moreover, we replicate also our main regression analyses on the system-level using the *MR* and *IRR* betas calculated from the three-factor models (Tables 2 and 3). As the results in both tables using both alternative three-factor models are almost identical to those in our main analysis, we do not present the tables here but are happy to provide them upon request. Overall, we conclude that the results from our two-factor state space model are not driven by any bias from omitting further risk factors known to be related to bank stock returns.

7 Conclusion

This paper is the first to measure the banking system's time-varying *MR* and *IRR* exposures using the Kalman filter. We thus provide new insight into the dynamics of systematic risk of the banking system. *MR* and *IRR* betas show substantial fluctuations over time at some points in time deviating from values expected in theoretical models of bank risk taking. The dynamics of the banking system's *MR* and *IRR* betas can be explained to a considerable degree by the development of the macro economy as well as by the state and structure of the banking system itself.

Further, we determine each bank's contribution to the banking system's *MR* and *IRR* betas and show that single banks have non-trivial leverage over the banking

Table 6 Correlations between risk factors and risk factor sensitivities

Panel A risk factors

	MR	*IRR*	*CR*
IRR	0.3067		
CR	−0.2187	−0.1004	
FXR	−0.1989	−0.0797	0.1273

Panel B betas from 2-factor and 3-factor models

	3-factor (+*CR*)	3-factor (+*FXR*)
MR 2-factor	0.9983	0.9972
IRR 2-factor	0.9960	0.9973

Panel A of this table shows correlations between different risk factor time-series in the period from 07/1997 to 12/2012. Panel B shows correlations between the *MR* (*IRR*) beta time-series from the 2-factor model (*MR* + *IRR*) and from 2 alternative 3-factor models adding credit risk (*CR*) and foreign exchange risk (*FXR*), respectively system's systematic risk exposure at specific times. We are able to explain such risk contributions using bank specific variables. We thus add to a better understanding of the dynamics underlying the banking system's systematic exposures to *MR* and *IRR* and facilitate timelier and more effective oversight for regulators and risk management for investors.

Appendix 1

See Table 7.

Table 7 List of macroeconomic variables

#	Tranf.	Description
1	lv	ISM manufacturing: production index
2	Δln	Real personal income
3	Δln	Real personal income excluding current transfer
4	Δln	Real manufacturing and trade industries sales
5	Δln	Real retail and food services sales
6	Δln	Industrial production index
7	Δln	Industrial production: final products (market group)
8	Δln	Industrial production: consumer goods
9	Δln	Industrial production: durable consumer goods
10	Δln	Industrial production: nondurable consumer goods
11	Δln	Industrial production: business equipment
12	Δln	Industrial production: materials
13	Δln	Industrial production: durable materials
14	Δln	Industrial production: nondurable materials
15	Δln	Industrial production: manufacturing (NAICS)
16	Δln	Industrial production: fuels
17	Δln	Personal consumption expenditures
18	Δlv	Capacity utilization: manufacturing (NAICS)
19	Δlv	Capacity utilization: total industry
20	Δln	Average weekly hours of production and nonsupervisory employees: manufacturing
21	Δln	ISM manufacturing: employment index
22	Δln	Average weekly hours of production and nonsupervisory employees: total private
23	Δlv	Unemployment rate: aged 15 and over: all persons for the United States
24	Δlv	Average (mean) duration of unemployment
25	Δlv	Weekly overtime hours: manufacturing for the United States
26	Δln	Civilian employment
27	Δln	Number of civilians unemployed—less than 5 weeks
28	Δln	Number of civilians unemployed for 5–14 weeks
29	Δln	Number of civilians unemployed for 15–26 weeks

Table 7 continued

#	Tranf.	Description
30	Δln	Number of civilians unemployed for 27 weeks and over
31	Δln	4-Week moving average of initial claims
32	Δln	All employees: total nonfarm
33	Δln	All employees: goods-producing industries
34	Δln	All employees: mining and logging
35	Δln	All employees: construction
36	Δln	All employees: manufacturing
37	Δln	All employees: durable goods
38	Δln	All employees: nondurable goods
39	Δln	All employees: service-providing industries
40	Δln	All employees: trade, transportation & utilities
41	Δln	All employees: wholesale trade
42	Δln	All employees: retail trade
43	Δln	All employees: financial activities
44	Δln	All employees: government
45	lv	ISM manufacturing: inventories index
46	lv	ISM manufacturing: supplier deliveries index
47	lv	ISM manufacturing: new orders index
48	lv	ISM manufacturing: PMI composite index
49	Δln	Value of manufacturers' new orders for consumer goods industries
50	Δln	Value of manufacturers' new orders for durable goods
51	Δln	Value of manufacturers' new orders for capital goods: nondefense capital goods
52	Δln	Value of manufacturers' unfilled orders for durable goods industries
53	Δln	Value of manufacturers' total inventories for all manufacturing industries
54	Δlv	Manufacturers: inventories to sales ratio
55	ln	Housing starts in west census region
56	ln	Housing starts in northeast census region
57	ln	Housing starts in midwest census region
58	ln	Housing starts in south census regions
59	ln	Housing starts in west census region
60	ln	New private housing units authorized by building permits
61	ln	New private housing units authorized by building permits in the northeast census region
62	ln	New private housing units authorized by building permits in the midwest census region
63	ln	New private housing units authorized by building permits in the south census region
64	ln	New private housing units authorized by building permits in the west census region
65	Δln	S&P 500 stock price index
66	Δln	Effective federal funds rate
67	Δln	3-month AA financial commercial paper rate
68	Δln	3-month treasury bill: secondary market rate
69	Δln	6-month treasury bill: secondary market rate
70	Δln	1-year treasury constant maturity rate
71	Δln	5-year treasury constant maturity rate

Table 7 continued

#	Tranf.	Description
72	Δln	10-year treasury constant maturity rate
73	Δln	Moody's seasoned Aaa corporate bond yield
74	Δln	Moody's seasoned Baa corporate bond yield
75	lv	3-months AA financial commercial paper federal funds rate spread
76	lv	3-months T-bill federal funds rate spread
77	lv	6-months T-bill federal funds rate spread
78	lv	1-year treasury constant maturity federal funds rate spread
79	lv	5-year treasury constant maturity federal funds rate spread
80	lv	0-year treasury constant maturity federal funds rate spread
81	lv	Moody's seasoned Aaa corporate bond yield federal funds rate spread
82	lv	Moody's seasoned Baa corporate bond yield federal funds rate spread
83	Δln	Trade-weighted US dollar index: major currencies
84	Δln	Switzerland/US foreign exchange rate
85	Δln	Japan/US foreign exchange rate
86	Δln	US/U.K. foreign exchange rate
87	Δln	Canada/US foreign exchange rate
88	$\Delta^2 ln$	M1 money stock
89	$\Delta^2 ln$	M2 money stock
90	$\Delta^2 ln$	St. Louis adjusted monetary base
91	$\Delta^2 ln$	Total reserve balances maintained with federal reserve banks
92	$\Delta^2 ln$	Reserves of depository institutions, non-borrowed
93	$\Delta^2 ln$	Total non-revolving credit owned and securitized, outstanding
94	$\Delta^2 ln$	Real M2 money stock
95	$\Delta^2 ln$	Producer price index: all commodities
96	$\Delta^2 ln$	Producer price index: finished goods
97	$\Delta^2 ln$	Producer price index: finished consumer goods
98	$\Delta^2 ln$	Producer price index: intermediate materials: supplies & components
99	$\Delta^2 ln$	Producer price index: crude materials for further processing
100	$\Delta^2 ln$	Consumer price index for all urban consumers: all items
101	$\Delta^2 ln$	Consumer price index for all urban consumers: apparel
102	$\Delta^2 ln$	Consumer price index for all urban consumers: transportation
103	$\Delta^2 ln$	Consumer price index for all urban consumers: medical care
104	$\Delta^2 ln$	Consumer price index for all urban consumers: commodities
105	$\Delta^2 ln$	Consumer price index for all urban consumers: durables
106	$\Delta^2 ln$	Consumer price index for all urban consumers: services
107	$\Delta^2 ln$	Consumer price index for all urban consumers: all items less food
108	$\Delta^2 ln$	Consumer price index for all urban consumers: all items less shelter
109	$\Delta^2 ln$	Consumer price index for all urban consumers: all items less medical care
110	$\Delta^2 ln$	Average hourly earnings of production and nonsupervisory employees: total private
111	$\Delta^2 ln$	Average hourly earnings of production and nonsupervisory employees: goods-producing
112	$\Delta^2 ln$	Average hourly earnings of production and nonsupervisory employees: construction
113	$\Delta^2 ln$	Average hourly earnings of production and nonsupervisory employees: manufacturing

Table 7 continued

#	Tranf.	Description
114	$\Delta^2 ln$	Average weekly hours of production and nonsupervisory employees: manufacturing
115	$\Delta^2 ln$	Personal consumption expenditures (implicit price deflator)
116	$\Delta^2 ln$	Personal consumption expenditures: durable goods (implicit price deflator)
117	$\Delta^2 ln$	Personal consumption expenditures: nondurable goods (implicit price deflator)
118	$\Delta^2 ln$	Personal consumption expenditures: services (implicit price deflator)
119	Δlv	University of Michigan: consumer sentiment

The first column shows the numbering of the macro variable. The second column indicates the transformation applied to the original data time series: lv denotes the level, ln denotes logarithm, Δln and $\Delta^2 ln$ denote the first and second difference of the logarithm, and Δlv denotes the first difference of the level of the series. Column three describes the original series

Appendix 2

See Table 8.

Table 8 Variable definitions

Variable	Description	Calculation	Sources
SIZE	Log of gross total assets, CPI-adjusted for 2006:Q1	$ln((BHCK2170 + BHCK3123 + BHCK3128) * 1000 * CPI_{2006:Q1}/CPI_t)$	US FED FR Y-9C report, Bureau of Labor Statistics
LEV	Total assets to total equity	$BHCK2170/BHCK3210$	US FED RF Y-9C report
DTrD/TLi	Demand and transaction deposits to total liabilities	$rcon2215/rcon2948$	Chicago FED Call Reports
RoA	Return on assets	$BHCK4340/BHCK2170$	US FED RF Y-9C report
NIM	Net interest margin	$BHCK4074/BHCK2170$	US FED RF Y-9C report
TCI/TL	Commercial and industrial loans to total loans	$(BHCK1763 + BHCK1764)/(BHCK2122 + BHCK2123)$	US FED RF Y-9C report
TL/TD	Total loans to total deposits	$(BHCK2122 + BHCK2123)/(BHDM6631 + BHDM6636 + BHFN6631 + BHDN6636)$	US FED RF Y-9C report
Lgrow	Quarterly relative loan growth	$(BHCK2122_t + BHCK2123_t)/(BHCK2122_{t-1} + BHCK2123_{t-1}) - 1$	US FED RF Y-9C report
loanHHI	Herfindahl–Hirschman-Index from the loan category shares	$(TCI/TL)^2 + \left(\frac{BHCK1590}{BHCK2122+BHCK2123}\right)^2 + \left(\frac{BHCB538+BHCK2011}{BHCK2122+BHCK2123}\right)^2 + \left(\frac{BHCK1410}{BHCK2122+BHCK2123}\right)^2 + (\text{other loans share})^2$	US FED RF Y-9C report
ALMM	Weighted average duration of assets minus liabilities	In accordance with English et al. (2012)	Chicago FED Call Reports
NPL	Non-performing loans to total assets	$(BHCK5525 + BHCK5526 - BHCK3506 - BHCK3507)/BHCK2170$	US FED RF Y-9C report
IncDiv	Income diversification	$1 - \text{abs}((BHCK4107 - BHCK4079)/(BHCK4107 + BHCK4079))$	US FED RF Y-9C report
LIQ	Liquid assets to total assets	$BHCK0010 + BHCK1754 + BHCK3545 + \begin{cases} BHCK1350 & 1997Q2 - 2001:Q4 \\ BHCKB987 + BHCKB989 & after 2001:Q4 \end{cases}$	US FED RF Y-9C report

References

Bessler W, Kurmann P (2014) Bank risk factors and changing risk exposures: capital market evidence before and during the financial crisis. J Financ Stab 13:151–166

Brunnermeier MK, Oehmke M (2013) The maturity rat race. J Financ 68(2):483–521

Brunnermeier MK, Dong G, Palia D (2012) Banks' non-interest income and systemic risk. Working Paper. Princeton University, Columbia University, Rutgers Business School. http://ssrn.com/abstract_id=1786738. Accessed 21 July 2016

Choudhry T, Wu H (2008) Forecasting ability of GARCH vs Kalman filter method: evidence from daily UK time-varying beta. J Forecast 27(8):670–689

Czaja M-C, Scholz H, Wilkens (2009) Interest rate risk of German financial institutions: the impact of level, slope, and curvature of the term structure. Rev Quant Financ Acc 33(1):1–26

Demsetz RS, Strahan PE (1997) Diversification, size, and risk at bank holding companies. J Money Credit Bank 29(3):300–313

Dewatripont M, Tirole J (1994) The prudential regulation of banks. MIT Press, Cambridge

Diamond DW, Dybvig PH (1983) Bank runs, deposit insurance, and liquidity. J Polit Econ 91(3):401–419

Elliott G, Müller UK (2006) Effcient tests for general persistent time variation in regression coefficients. Rev Econ Stud 73(4):907–940

English WB, Van den Heuvel SJ, Zakrajsek E (2012) Interest rate risk and bank equity valuations. FEDS Working Paper 2012–26. http://www.federalreserve.gov/pubs/feds/2012/201226/201226pap.pdf. Accessed 21 July 2016

Entrop O, von la Hausse L, Wilkens M (2016) Looking beyond banks' average interest rate risk: Determinants of high exposures. Q Rev Econ Financ. doi:10.1016/j.qref.2016.04.008

Farhi E, Tirole J (2012) Collective moral hazard, maturity mismatch, and systemic nailouts. Am Econ Rev 102(1):60–93

Flannery MJ, James CM (1984) The effect of interest rate changes on the common stock returns of financial institutions. J Financ 39(4):1141–1153

Froot KA, Stein JC (1998) Risk management, capital budgeting, and capital structure policy for financial institutions: an integrated approach. J Financ Econ 47(1):55–82

Gorton G, Metrick A (2012) Securitized banking and the run on repo. J Financ Econ 104(3):425–451

Gropp R, Kok C, Lichtenberger JD (2007) The dynamics of bank spreads and financial structure. Q J Financ 4(4):1450014.1–1450014.53

Gurkaynak RS, Sack B, Wright JH (2007) The US treasury yield curve, 1961 to the present. J Monet Econ 54(8):2291–2304

Hanson SG, Shleifer A, Stein JC, Vishny RW (2015) Banks as patient fixed income investors. J Financ Econ 117:449–469

Hellwig M (1994) Liquidity provision, banking, and the allocation of interest rate risk. Eur Econ Rev 38(7):1363–1389

Hellwig M (1998) Financial institutions in transition: banks, markets, and the allocation of risks in an economy. J Inst Theor Econ 154(1):328–345

Hirtle B (1997) Derivatives, portfolio composition, and bank holding company interest rate risk exposure. J Financ Serv Res 12(2–3):243–266

Hoerdahl P, King, MR (2008) Developments in Repo Markets During the Financial Turmoil. BIS Quarterly Review 12/2008. http://www.bis.org/publ/qtrpdf/r_qt0812e.pdf. Accessed 21 July 2016

Hovakimian A, Kane EJ, Laeven L (2012) Variation in systemic risk at US banks during 1974–2010. NBER Working Paper 18043. http://www.nber.org/papers/w18043. Accessed 21 July 2016

Ince OS, Porter RB (2006) Individual equity return data from Thomson Datastream: handle with care. J Financ Res 29(4):463–479

Jagannathan R, Wang Z (1996) The conditional CAPM and the cross-section of ex-pected returns. J Financ 51(1):3–53

Kaiser HF (1958) The varimax criterion for analytic rotation in factor analysis. Psychometrika 23:187–200

Kane EJ, Unal H (1988) Change in market assessments of deposit-institution riskiness. J Financ Serv Res 1(3):207–229

Kane EJ, Unal H (1990) Modeling structural and temporal variation in the market's valuation of banking firms. J Financ 45(1):113–136

Kashyap AK, Rajan R, Stein JC (2002) Banks as liquidity providers: an explanation for the coexistence of lending and deposit-taking. J Financ 57(1):33–73

Kaufman GG (1984) Measuring and managing interest rate risk: a primer. Econ Perspect 8(1):16–29

Laeven L, Levine R (2007) Is there a diversification discount in financial conglomerates? J Financ Econ 85:331–367

Litterman R, Scheinkman J (1991) Common Factors Affecting Bond Returns. J Fixed Income 1(1):54–61

Ludvigson SC, Ng S (2009) Macro factors in bond risk premia. Rev Financ Stud 22(12):5027–5067

Mamaysky H, Spiegel M, Zhang H (2008) Estimating the dynamics of mutual fund alphas and betas. Rev Financ Stud 21(1):233–264

Marcus AJ (1984) Deregulation and bank financial policy. J Bank Financ 8(4):557–565

Mergner S, Bulla J (2008) Time-varying beta risk of Pan-European industry portfolios: a comparison of alternative modeling techniques. Eur J Financ 14(8):771–802

Merton RC (1977) An analytic derivation of the cost of deposit insurance and loan guarantees an application of modern option pricing theory. J Bank Financ 1(1):3–11

Nelson CR, Siegel AF (1987) Parsimonious modeling of yield curves. J Bus 60(4):473–489

Patton AJ, Verardo M (2012) Does beta move with news? Firm-specific information flows and learning about profitability. Rev Financ Stud 25(9):2789–2839

Schrand C, Unal H (1998) Hedging and coordinated risk management: evidence from thrift conversions. J Financ 53(3):979–1013

Staikouras SK (2006) Financial intermediaries and interest rate risk: II. Financ Mark Inst Instrum 15(5):225–272

Stock JH, Watson MW (2002) Macroeconomic forecasting using diffusion indexes. J Bus Econ Stat 20(2):147–162

Stone BK (1974) Systematic interest-rate risk in a two-index model of returns. J Financ Quant Anal 9(5):709–721

Toevs AL (1983) Gap Management: Managing interest rate risk in banks and thrifts. In: Federal Reserve Bank of San Francisco (ed.): Economic Review 9(1):20–35

Whited TM, Wu G (2006) Financial constraints risk. Rev Financ Stud 19(2):531–559

Zagonov M (2011) Securitization and bank intermediation function. Working Paper. Toulouse Business School. http://ssrn.com/abstract_id=1663061. Accessed 21 July 2016